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ARMY MEDICAL RESEARCH LABORATORY

FORT KNOX, KENTUCKY

REPORT NO. 233
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THE ACCURACY OF CONSTANT ANGULAR DISPLACEMENT OF THE ARM IN THE HORIZONTAL PLANE AS INFLUENCED BY THE DIRECTION AND LOCUS OF THE PRIMARY ADJUSTIVE MOVEMENT*

*Subtask under Psychophysiological Studies, AMRL Project No. 6-95-20-001, Subtask, Control Coordination Problems.

RESEARCH AND DEVELOPMENT DIVISION
OFFICE OF THE SURGEON GENERAL
DEPARTMENT OF THE ARMY

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ABSTRACT

THE ACCURACY OF CONSTANT ANGULAR DISPLACEMENT OF THE ARM IN THE HORIZONTAL PLANE AS INFLUENCED BY THE DIRECTION AND LOCUS OF THE PRIMARY ADJUSTIVE MOVEMENT

OBJECT

To determine the effect of the direction of primary adjustment on the accuracy of estimating small (10^{o}) displacements of the right arm in the horizontal plane, and the manner in which accuracy is influenced by the locus of movement.

RESULTS

When the primary adjustive movement was toward the side, greater accuracy was obtained in the side region (50^{o}-90^{o}) than in the front region (0^{o}-40^{o}). When the primary adjustment was toward the front, greatest accuracy was obtained in the front region. When the locus of movement was disregarded, adjustments toward the side were more accurate than those toward the front. The influence of direction of adjustment on accuracy was greatest in the side region.

There was a tendency to underestimate the extent of adjustive movements toward the side when they were made near the front and to overestimate them when they were made near the side. There was a general tendency to underestimate the extent of movement when the adjustment was toward the front. Practice resulted in a significant decrease in variability, but not in the extent and direction of the errors.

CONCLUSIONS

The results strongly support the hypothesis that movements made with increasing muscular tension are more accurate than those made with decreasing tension. The results indicate the following relationships between the locus and direction of movement of a control and the accuracy with which adjustments can be made in the horizontal plane: 1) Adjustments toward the front are more accurate than those toward

the side when the control is located in front of the operator; 2) Adjustments toward the side are more accurate than those toward the front when the control is located at the operator's side; 3) In general, adjustments toward the side are more accurate than those toward the front; 4) When the control is located in front of the operator it can be adjusted more accurately than when it is located at his side; 5) The direction of adjustment affects accuracy more when the control is located at the operator's side than when it is in front. These results may be anticipated when the forces affecting movement of the control are derived primarily from the musculature of the arm.

RECOMMENDATIONS

Studies should be continued on the effects of position and direction of movement of a control on the accuracy with which it can be manipulated.

Submitted 24 January 1956 by:

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THE ACCURACY OF CONSTANT ANGULAR DISPLACEMENT OF THE ARM IN THE HORIZONTAL PLANE AS INFLUENCED BY THE DIRECTION AND LOCUS OF THE PRIMARY ADJUSTIVE MOVEMENT

I. INTRODUCTION

In the operation of complex equipment an operator often has the task of locating and manipulating controls without the aid of visual cues. In operating equipment under blackout conditions, or in the operation of a control which is temporarily out of the field of vision, the placement of a control, its plane of operation, characteristic direction of movement, etc., may be of great importance. Fitts (3) and Caldwell and Herbert (2) show that positions in front of the subject tend to be located more accurately than those to the side. In the study by Caldwell and Herbert a relationship was found between the size and direction of the error in localizing a position in space and the direction of movement of the arm to that position. They found that when the arm was moved toward the side, the angular positions near the front tended to be overshot and those near the side tended to be undershot. When the arm was moved toward the front there was a general tendency to overshoot all positions. Brown, Knauft and Rosenbaum (1) found that positioning reactions away from the body were more accurate than those toward the body.

The object of the present investigation was to study the effect of locus and direction of movement on the accuracy with which 10^{o} movements of the arm could be made in the horizontal plane. In the studies on the accuracy of locating spatial positions (2 and 3), the results are ambiguous in that the error obtained at a given position is probably a function of both the spatial position itself and the distance the arm moves from the starting position to the goal position. For example, in the Fitts' study, in which all movements were initiated from a position in front of the subject, the results could be interpreted to mean either that accuracy of localization decreases as the positions move to the side, or that the accuracy of arm movements decreases as the arm excursion increases. In the Caldwell and Herbert study each angular position was estimated from all other positions on the scale. That is, there were variable extents of movement involved in the estimation of a position. Unfortunately, it was not possible to have the same extents of movement for all positions. One obvious way of eliminating the confounding between spatial position and extent of movement would be to hold the movement constant for all positions, but then the subject may interpret the task simply as one of estimating the displacement of the arm.

Right and left adjustive movements were made in the region between 0^{o} and 90^{o} in the horizontal plane. (0^{o} represents the intersection of the horizontal and medial planes passing through the shoulder joint and 90^{o} represents the intersection of the horizontal and lateral planes.) The locus of movement was indicated by the angular position to which the arm would point if it had been moved exactly 10^{o}. (The starting positions of the arms were at 0^{o}, 10^{o}, 30^{o}, etc.). Hypotheses derived from the results of this previous study (2) and tested in the present one were: 1) The accuracy of estimating displacement of the arm will be greater when the primary adjustive movement is toward the side than when it is toward the front; 2) For the movements toward the front adjustments in the region between 0^{o} and 40^{o} will be more accurate than those between 50^{o} and 90^{o}, and for the movements toward the side greatest accuracy will be obtained in the 50^{o}-90^{o} region; and 3) The effect of direction of movement on accuracy will be less in the front region (0^{o}-40^{o}) than in the side region (50^{o}-90^{o}).

II. EXPERIMENTAL

A. Apparatus

The apparatus shown in Figure 1 consists of a padded sleeve suspended from a boom by broad rubber bands. The boom is connected to a vertical ball-bearing-mounted shaft. A pointer connected to the shaft rides over a plate on which an angular scale is etched. The scale is divided into 1^{o} units. The apparatus can be raised or lowered to compensate for variations in the trunk lengths of the subjects. The range of adjustment is sufficient for use by subjects seated or standing though subjects were seated in this study. The movement of the shaft was sufficiently free so that at no time did a subject report that the apparatus was hindering movement of the arm. This apparatus was used to provide a comfortable support for the arm and an accurate indication of its position in the horizontal plane.

B. Subjects

The 12 subjects employed in this investigation were drawn in an unbiased manner from a pool of 50 volunteer experimental subjects who were on duty with the laboratory. None of the subjects had been involved in a study sufficiently similar to the present one that transfer effects might be expected.

C. Procedure

On the first day the experimenter outlined the general procedure of the experiment to the subjects and demonstrated the apparatus to be used. The subjects were informed that they would be required to make 10° movements of their right arms and that the starting position would vary from trial to trial between -10° and 100°. They were informed that 0° represented the point directly in front of the right shoulder and that the 90° position was 90° clockwise from 0°. Each subject was seated so that the point of rotation of his arm was directly beneath the vertical shaft. The height of the apparatus was set so that when the arm was moved to the side positions, the end of the shaft barely cleared the subject's shoulder. In this position the hand was at shoulder height. The positions of the chair and apparatus were determined for each subject so that immediate adjustments could be made in all future sessions. The criterion of proper adjustment was a report of the subject that he could move his arm to the left and right with the feeling that he was doing so without any aid or hindrance from the apparatus.

The subjects were tested once a day for a total of 20 days. Each subject made 40 trials every day - 20 practice trials and 20 test trials. Each set of trials consisted of 2 trials for each of the 10 positions at 10° intervals from 0° through 90°. For half of the trials the adjustive movements were toward the side (10° to 20°, 20° to 30°, etc.) and for the other half the movements were toward the front (20° to 10°, 30° to 20°, etc.). At the beginning of each trial the subject was told the starting position of his arm and the point at which he brought his arm to rest. For example, a subject was told that his arm was at 40° and that on the signal "go" he was to move to 50° and to say "50°" when he was satisifed with the setting he had made. He was then told the position at which he brought his arm to rest and, consequently, how far he had moved his arm. Thus, after each trial the subject knew exactly how much he had overestimated or underestimated a 10° movement. The subjects were advised of the accuracy of their performance in order to foster intra-subject competition.

III. RESULTS

There are 2 measures of the accuracy with which the subjects estimated 10° angular displacements of their arms - the constant error and the variable error. The constant error (CE) was obtained by adding the errors of estimation algebraically and dividing by the number of trials. Thus, the CE indicates the mean extent and direction of the error. For example, a CE of 2° means that, on the average, the subjects moved 2° too far or that they moved 12°. A CE of -2° means that the subjects moved their arms only 8°. The standard deviation (SD) which was used as the measure of the variable error, indicates the dispersion of the scores about the mean. An SD of 2^{o} means that approximately 68% of the errors were 2^{o} or less on either side of the mean.

The CE's obtained in the present study are shown in Tables 1 and 3, and the SD's are given in Tables 2 and 4. In Tables 1 and 2 the mean errors are given for the 10 positions (0^{o} through 90^{o}) for the first and second halves of the trials and for total trials for the 2 directions of movement. Each entry in columns 2, 3, 5 and 6 of Tables 1 and 2 is based on 10 trials by each of the 12 subjects, and the entries in columns 4 and 7 are based on 20 trials by each subject. The SD's in Table 2 are the means of the SD's for the 12 subjects. In Tables 3 and 4 the mean errors are given for the 12 subjects for the adjustments made in the left (0^{o}-40^{o}) and right (50^{o}-90^{o}) halves of the scale and for the entire scale for the 2 directions of movement. The CE's are shown in Table 3 and the SD's are given in Table 4. The entries in columns 2, 3, 5 and 6 of these tables are based on 100 scores (20 trials to each of the 5 angular positions) for each subject and the entries in columns 4 and 7 are based on 200 scores.

The primary object of the present experiment was to study the influence of the direction and locus of movement on the accuracy of estimating a small arm displacement in the horizontal plane. Since measurements were made on the same subjects over an extensive period, it was necessary to examine the results for possible effects of practice on performance.

From an examination of Figure 2 and column 8 of Table 1 it may be seen that there was no consistent relationship between the position of the arm and the CE's when the direction of movement was disregarded. It is obvious from this figure and columns 4 and 7 of Table 1 that the direction of primary adjustment had an effect on the CE's. When the adjustment was made in the lower half of the scale (0^{o}-40^{o}) and the movement was toward the side (column 2 of Table 3) there was a tendency to move the arm too far. When the adjustment was made in the upper half of the scale (50^{o}-90^{o}) and was toward the side (column 3 of Table 3) there was a tendency not to move the arm far enough. When the adjustment was toward the front (columns 5 and 6 of Table 3) there was a general tendency to move the arm too far.

It may be seen also that adjustments toward the side were more accurate than those toward the front. The mean CE for all adjustments toward the side was $+0.31^{o}$ and for all adjustments toward the front the mean CE was $+1.10^{o}$. A test of the difference between the mean CE's for the 2 directions yielded a *t* of 2.219, which was significant at less than the 3% level of confidence. This probability and those given for the tests indicated in Table 5 are one-half those shown in the conventional *t*-table. The one-tailed test was used in these cases because the directions of the differences were predicted.

Figure 3 and columns 4 and 7 of Table 2 indicate that the least variability in judging arm displacement was evident when the movement occurred in the regions adjacent to the extremes of the scale (10° and 80°). For both directions of movement the greatest accuracy was obtained at the 10° and 20° positions. Also, it may be seen that performance was more stable when the adjustive movement was toward the side than when it was toward the front. For this comparison see columns 4 and 7 of Table 2. A statistical test of the differences between the mean standard deviations for the 2 directions of movement yielded a *t* of 1.980 ($p < .05$).

As shown in Figure 4 and columns 2, 3, 5 and 6 of Table 1, practice did not result in a systematic reduction in the CE's. There was an increase in the mean CE's for the side movements and a slight decrease in the mean CE's for the front movements. In neither case was the change significant. The *t's* for the 2 comparisons were 1.764 and 0.686, respectively. It should be noted that the curves for side and front adjustments shown in Figure 2 fall midway between the corresponding pairs of curves shown in Figure 4. A test of the difference between the CE's for the 2 directions of movement for the first and second halves of the trials yielded a *t* of 1.18 which does not reach significance at the 5% level of confidence. This test was made to determine if the effect of direction of adjustment on the CE decreased with practice.

From Figure 5 and columns 3 and 6 of Table 2, it may be seen that practice resulted in a reduction in variability for both the side and front movements. The *t's* were 2.571 and 2.236, respectively. Both *t's* are significant at less than the 3% level of confidence. A test of the difference between the mean SD's for the 2 directions of adjustment for the 2 halves of trials yielded a *t* of 0.038. This test was done to determine if the difference in variability between the side and front adjustments was affected by practice. Thus, practice resulted in a general decrease in variability, but there was no appreciable change in the differential effect of the direction of movement on variability. In Table 4 it is shown that for both directions of adjustment there was greater variability in the 50°-90° region than in the 0°-40° region, but this difference was slight.

From the results of a previous study it was hypothesized that under the conditions of the present investigation movements toward the extreme positions would be more accurate than those away from the extremes. In other words, it was expected that for movements toward the side the greatest accuracy would be obtained between 50° and 90°, and for movements toward the front the greatest accuracy would be obtained in the region between 0° and 40°. A comparison of the mean CE's for the adjustments toward the side between 0° and 40° and between 50° and 90° yielded a *t* of 2.247 ($p < .03$). For this comparison see columns 2 and 3 of Table 3. The same test of the mean CE's for the adjustments toward the front (columns 5 and 6 of Table 3) yielded a *t* of 2.335 ($p < .03$). Thus, the hypothesis was supported strongly in both cases.

It was hypothesized also that the influence of direction would be less in the 0°-40° region than in the 50°-90° region. A test of the difference between the mean CE's for the 2 directions of movement in the 0°-40° region yielded a *t* of 1.198. For this comparison see columns 2 and 5 of Table 3. This difference was not significant at the minimum acceptable (5%) level of confidence. The *t* of 2.937 derived from the test of the mean CE's for the 2 directions of movement in the 50°-90° region (columns 3 and 6 of Table 3) was significant at less than the 1% level of confidence. The above tests were repeated for the SD's and in no case was a significant *t* obtained.

IV. DISCUSSION AND CONCLUSIONS

In a study on the accuracy of localizing spatial positions in the horizontal plane in the absence of visual cues (2) it was found that the angular positions were more accurately located when the arm was moved toward the side than when it was moved toward the front. Also, the data indicated that moving the arm against increasing tension resulted in greater accuracy than moving it with decreasing tension. That is, adjustments made toward the extreme positions are more accurate than those made away from the extremes. From direct experience and the reports of the subjects it is known that opposition to movement increases as the extended arm approaches the extreme front and side positions and that the build-up of tension is more noticeable at the side than at the front.

With the above considerations in mind the following predictions were made concerning performance in the present task: 1) Adjustive movements toward the side will be more accurate than those toward the front; 2) For movements toward the side, performance will be more accurate in the 50^{o}-90^{o} regions than in the 0^{o}-40^{o} regions; 3) For movements toward the front, performance will be more accurate in the 0^{o}-40^{o} region than in the 50^{o}-90^{o} region; and 4) The influence of direction on accuracy will be greatest in the 50^{o}-90^{o} region.

All the above hypotheses were supported by the data. Thus, there is convincing evidence of a significant interaction between the optimum placement and direction of movement of an unloaded control. This relationship can be seen in Figure 2. There was only one point at which the predictions did not hold. At 40^{o}, movements toward the side were more accurate than those toward the front. Division of the scale at its mid-point was purely arbitrary for there was no way of knowing beforehand the point at which the muscular forces aiding and opposing movement reached an equilibrium. The results suggest that the indifference point is near 30^{o} rather than 45^{o}. This is consistent with the reports of the subjects that the forces affecting movement are more noticeable in the side region than in the front.

One very interesting aspect of the present investigation is the manner in which practice affected the performance. With practice there was a significant increase in the stability of performance but no appreciable change in the direction and mean extent of the errors. This is rather unusual in view of the fact that each subject had 800 trials and on each trial he was informed immediately of the direction and extent of his error. From this result one would conclude that the immediate recall of the pattern of kinesthetic cues associated with slight movement of the arm was so poor that it was not adequate to support learning after the initial gross errors were eliminated. The results of this study indicate the following relationships between the locus and direction of movement of a control and the accuracy with which adjustments can be made in the horizontal plane: 1) Adjustments toward the front are more accurate than those toward the side when the control is located in front of the operator; 2) Adjustments toward the side are more accurate than those toward the front when the control is located at the operator's side; 3) In general, adjustments toward the side are more accurate than those toward the front; 4) In general, a control located in front of the operator can be adjusted more accurately than one located at his side; 5) The direction of adjustment affects accuracy more when the control is located at the operator's side than when it is in front.

The above results may be anticipated when the forces affecting movement of the control are derived primarily from the musculature of the arm.

V. RECOMMENDATIONS

Studies should be continued on the effects of position and direction of movement of a control on the accuracy with which it can be manipulated. In addition, the effects of various kinds of control loading on this performance should be investigated.

VI. BIBLIOGRAPHY

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TABLE 1

MEAN CONSTANT ERRORS IN DEGREES FOR 10° ANGULAR DISPLACEMENTS OF THE RIGHT ARM EXECUTED AT VARIOUS LOCI IN THE HORIZONTAL PLANE. (Data Given for the First and Second Halves of Trials for Both Directions of Adjustment with the Mean for Total Trials at Each Locus)

	ADJUSTMENT TOWARD SIDE			ADJUSTMENT TOWARD FRONT			
Locus of Movement*	First Half	Second Half	Total	First Half	Second Half	Total	Total Trials
Column 1	2	3	4	5	6	7	8
0°	1.65	0.81	1.23	0.52	0.88	0.70	0.96
10°	1.36	0.72	1.04	-0.35	-0.06	-0.20	0.42
20°	1.49	0.67	1.08	0.23	0.21	0.22	0.65
30°	0.99	1.04	1.02	0.88	1.08	0.98	1.00
40°	0.28	1.10	0.69	1.79	0.98	1.38	1.04
50°	-0.21	0.35	0.07	1.28	0.53	0.90	0.48
60°	-0.36	0.19	-0.08	1.22	1.07	1.14	0.53
70°	-1.00	-0.02	-0.51	1.58	1.13	1.35	0.42
80°	-1.15	-0.27	-0.71	1.82	1.86	1.84	0.56
90°	-1.14	-0.25	-0.70	2.91	2.48	2.70	1.00
Mean	0.19	0.43	0.31	1.19	1.02	1.10	0.71

*Indicates the terminal position of the arm if an exact 10° movement were made.

TABLE 2

MEAN STANDARD DEVIATIONS IN DEGREES FOR 10° ANGULAR DISPLACEMENTS OF THE RIGHT ARM EXECUTED AT VARIOUS LOCI IN THE HORIZONTAL PLANE. (Data Given for the First and Second Halves of Trials for Both Directions of Adjustment with the Mean for Total Trials at Each Locus)

	ADJUSTMENT TOWARD SIDE			ADJUSTMENT TOWARD FRONT			
Locus of Movement*	First Half	Second Half	Total	First Half	Second Half	Total	Total Trials
Column 1	2	3	4	5	6	7	8
0°	1.95	1.60	1.92	2.16	1.64	2.03	2.31
10°	1.81	1.55	1.81	1.62	1.76	1.79	1.94
20°	1.88	1.60	1.85	1.90	1.66	1.85	2.01
30°	2.00	1.65	1.95	2.34	1.84	2.23	2.36
40°	1.91	1.64	1.92	2.18	1.76	2.13	2.30
50°	2.22	1.64	2.03	2.43	1.61	2.21	2.22
60°	1.85	1.65	1.86	2.07	1.79	2.06	2.08
70°	2.05	1.77	2.08	2.02	1.88	2.09	2.15
80°	2.13	1.54	2.00	1.91	1.95	1.97	2.15
90°	2.02	1.68	2.00	2.38	1.82	2.42	2.48
Mean	1.98	1.63	1.94	2.10	1.77	2.08	2.20

*Indicates the terminal position of the arm if an exact 10° movement were made.

TABLE 3

MEAN CONSTANT ERRORS IN DEGREES FOR ADJUSTMENTS TOWARD THE FRONT AND SIDE IN THE REGIONS 0°-40°, 50°-90° AND 0°-90° FOR THE 12 SUBJECTS

	ADJUSTMENT TOWARD SIDE			ADJUSTMENT TOWARD FRONT		
Subjects	0°-40°	50°-90°	0°-90°	0°-40°	50°-90°	0°-90°
Column 1	2	3	4	5	6	7
1	0.72	-0.38	0.17	0.94	1.28	1.11
2	1.33	-0.62	0.36	1.10	2.16	1.63
3	-0.44	0.46	0.01	1.31	0.73	1.02
4	1.05	-0.98	0.04	-0.63	2.46	0.92
5	1.10	-0.97	0.06	0.92	2.80	1.86
6	-0.60	0.28	-0.16	1.83	1.56	1.70
7	1.11	-0.39	0.36	0.08	1.52	0.80
8	0.83	0.12	0.48	-0.28	0.68	0.20
9	1.84	0.11	0.98	0.75	1.58	1.16
10	1.21	-0.85	0.18	0.40	2.24	1.32
11	1.01	-0.87	0.07	1.15	1.40	1.28
12	2.92	-0.60	1.16	-0.18	0.64	0.23
Mean	1.01	-0.39	0.31	0.62	1.59	1.10

TABLE 4

MEAN STANDARD DEVIATIONS IN DEGREES FOR ADJUSTMENTS TOWARD THE FRONT AND SIDE IN THE REGIONS 0°-40°, 50°-90° AND 0°-90° FOR THE 12 SUBJECTS

	ADJUSTMENT TOWARD SIDE			ADJUSTMENT TOWARD FRONT		
Subjects	0°-40°	50°-90°	0°-90°	0°-40°	50°-90°	0°-90°
Column 1	2	3	4	5	6	7
1	1.48	1.59	1.53	1.46	1.47	1.47
2	2.08	1.97	2.03	2.06	2.19	2.12
3	1.72	1.85	1.78	2.08	2.09	2.08
4	1.65	1.60	1.82	1.95	1.81	2.06
5	2.18	2.32	2.25	2.40	2.60	2.50
6	1.61	1.54	1.58	1.56	2.16	1.86
7	1.66	1.87	1.76	1.83	2.03	1.93
8	1.61	2.18	1.90	2.10	1.87	1.99
9	2.20	2.20	2.20	2.68	2.48	2.58
10	2.00	2.48	2.24	1.96	2.36	2.16
11	2.21	1.92	2.06	2.11	2.50	2.31
12	2.28	2.03	2.15	1.87	1.90	1.88
Mean	1.89	1.96	1.94	2.01	2.12	2.08

TABLE 5

SUMMARY OF *t*-TESTS OF PAIRS OF STATISTICS LISTED IN FIRST COLUMN

	Comparison	*t*	*df*	*p*
1.	Mean CE's for adjustments toward the side and front	2.219	11	<.03*
2.	Mean SD's for adjustments toward the side and front	1.980	11	<.05*
3.	Mean CE's for adjustments toward the side for the first and second halves of trials	1.764	11	----
4.	Mean CE's for adjustments toward the front for the first and second halves of trials	0.686	11	----
5.	Difference between the mean CE's for adjustments toward the side and front for the first and second halves of trials	1.180	11	----
6.	Mean SD's for adjustments toward the side for the first and second halves of trials	2.571	11	<.03*
7.	Mean SD's for adjustments toward the front for the first and second halves of trials	2.236	11	<.03*
8.	Difference between the mean SD's for adjustments toward the side and front for the first and second halves of trials	0.038	11	----
9.	Mean CE's for adjustments toward the side between 0° and 40°, and 50° and 90°	2.247	11	<.03*
10.	Mean CE's for adjustments toward the front between 0° and 40°, and 50° and 90°	2.335	11	<.03*
11.	Mean CE's for adjustments toward the side and front between 0° and 40°	1.198	11	----*
12.	Mean CE's for adjustments toward the side and front between 50° and 90°	2.937	11	<.01*
13.	Mean SD's for adjustments toward the side between 0° and 40°, and 50° and 90°	0.925	11	----
14.	Mean SD's for adjustments toward the front between 0° and 40°, and 50° and 90°	1.425	11	----
15.	Mean SD's for adjustments toward the side and front between 0° and 40°	1.360	11	----
16.	Mean SD's for adjustments toward the side and front between 50° and 90°	1.670	11	----

* p obtained from one-tailed test

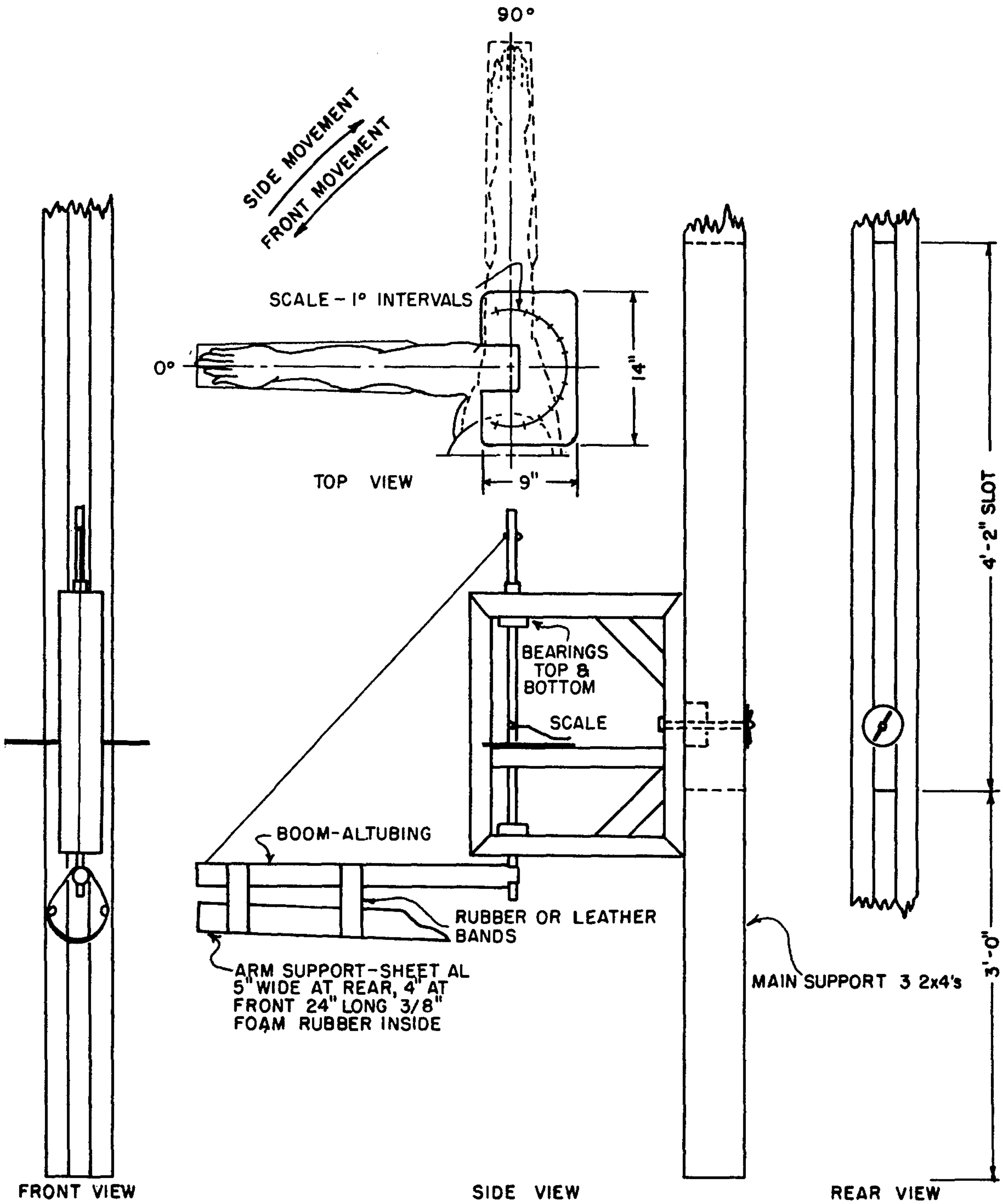

FIG I. ARM KINESTHESIOMETER

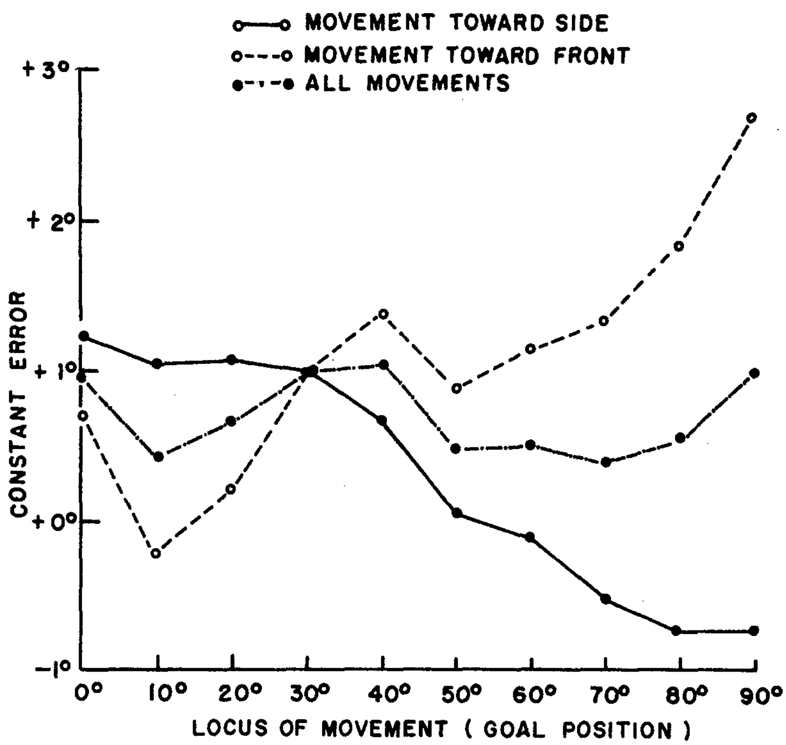

FIG. 2 MEAN CONSTANT ERRORS FOR 10° MOVEMENTS OF THE ARM TOWARD THE FRONT AND SIDE AT VARIOUS LOCI IN THE HORIZONTAL PLANE.

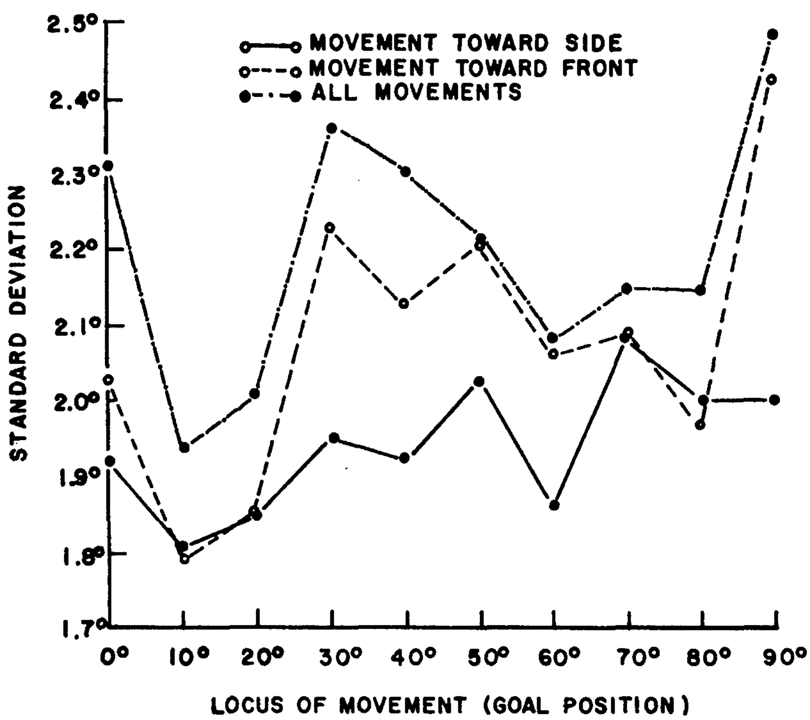

FIG. 3 MEAN STANDARD DEVIATIONS FOR 10° MOVEMENTS OF THE ARM TOWARD THE FRONT AND SIDE AT VARIOUS LOCI IN THE HORIZONTAL PLANE.

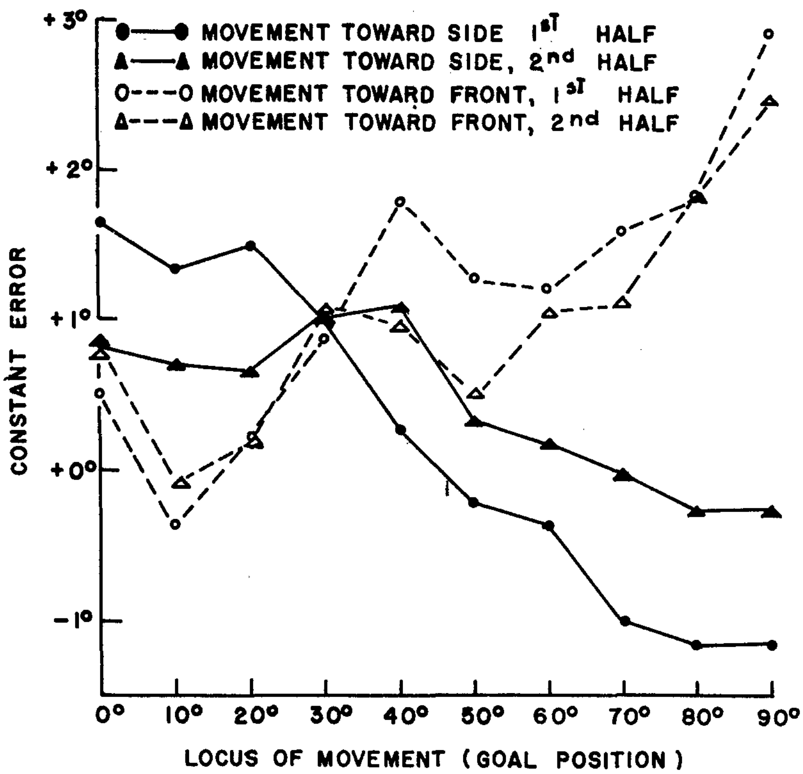

FIG. 4 MEAN CONTANT ERRORS FOR THE FIRST AND SECOND HALVES OF TRIALS FOR 10° MOVEMENTS OF THE ARM TOWARD THE FRONT AND SIDE AT VARIOUS LOCI IN THE HORIZONTAL PLANE.

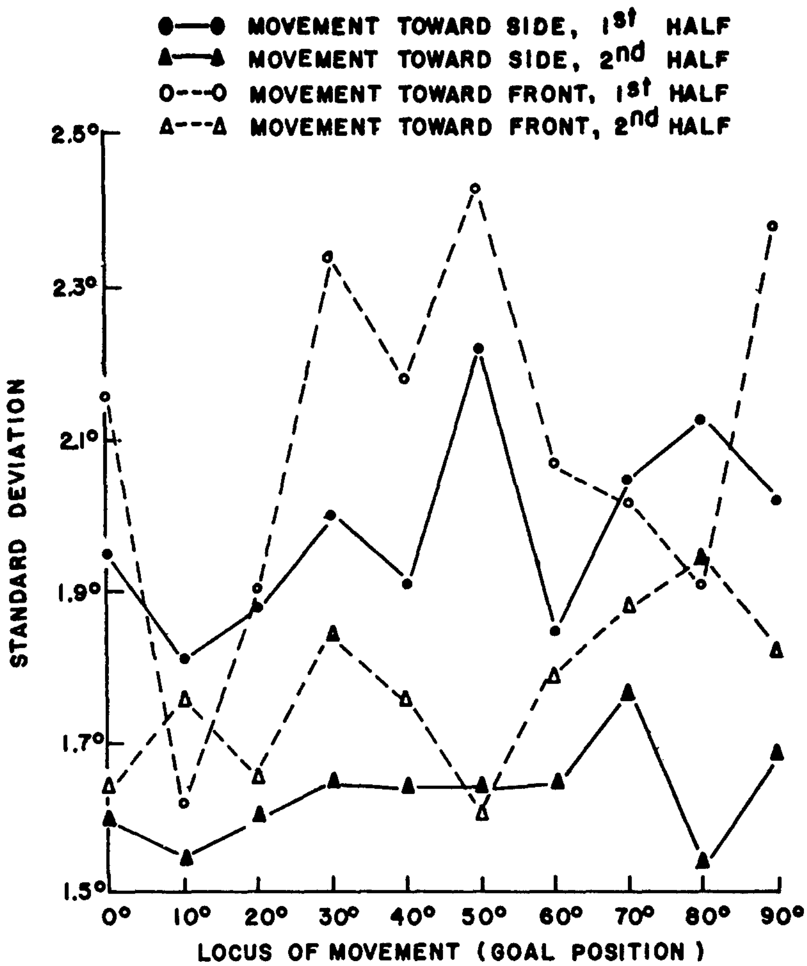

FIG. 5 MEAN VARIABLE ERRORS FOR THE FIRST AND SECOND HALVES OF TRIALS FOR 10° MOVEMENTS OF THE ARM TOWARD THE FRONT AND SIDE AT VARIOUS LOCI IN THE HORIZONTAL PLANE.

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